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INTEGRATING RENEWABLES IN MINING: REVIEW OF BUSINESS MODELS AND POLICY IMPLICATIONS

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Abstract

Mining activities are energy-intensive and rely largely on fossil fuels to meet their energy demands. This exposes the mining sector to potential policy and regulatory risks, stemming from government efforts to shift the global economy to a low-emission development pathway, as envisaged by the Paris Agreement. At the same time, renewables have become an increasingly cost-competitive source of power generation. This has resulted in a business case for the adoption of solar and wind energy solutions in the mining sector, to reduce costs as well as carbon footprint of operations. The sector's energy transition also presents an opportunity for resource-rich countries, including developing economies, to foster the synergistic development of higher value-added domestic activities in the renewable energy sector. The shift of the mining industry to low-carbon energy has the potential to contribute to advancing the climate and sustainable development agenda, while also pursuing economic diversification objectives. However, the integration of new technologies into conventional power systems comes with risks and challenges. This paper aims to enhance the understanding of the key drivers for, and obstacles to, renewable energy integration in mining operations, based on a review of over 30 existing projects worldwide. The analysis identifies a need for an enabling policy environment, encompassing among others a competitive energy market structure and adequate energy infrastructure, to overcome current challenges and support the synergies between the development of the mining and renewable energy sectors.

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Executive summary

Both the 2015 Paris Agreement to combat climate change and the 2030 Agenda for Sustainable Development clearly identify the urgency for the global economy to shift to a low-emission development pathway, to avoid future costly effects of climate change for development, while also improving access to reliable, affordable and clean energy. Resource-rich countries, in particular developing economies heavily reliant on the extractive sector, will inevitably face the need to put their economy on a more sustainable footing, in order to maintain their competitiveness in a low-carbon future.

Fossil fuels remain a dominant energy source for both grid-connected and off-grid mines, making the sector one of the top greenhouse gas emitters and increasing exposure to potential policy and regulatory risks. These include the tightening of climate change-related regulations, to constrain the use of fossil fuels, and the resulting changes in overall global consumption and investment patterns, which can negatively affect the competitiveness of mining emission-intensive operations. The dependence on fossil fuels is also fraught with significant price volatility and low-quality energy supply, associated with energy and transport infrastructure gaps, particularly in developing economies and geographically dispersed sparsely populated countries. As a result, mining companies have come under increasing internal and external pressure to hedge risks and improve efficiency, by reducing energy consumption costs.

In the context of the steady cost decline in renewable energy technology over the past years, solar and wind power solutions have become increasingly attractive to mines as a complement to their fossil fuel-based off-grid or grid-connected energy mix. Latin America, particularly Chile and Mexico, is leading the way in utility-scale renewable energy projects for mines, with Australia, Canada as well as South Africa also emerging as potential hubs. Several business models are being employed – self-generation, corporate power purchase agreements, rental and re-deployable solutions – to meet mines' varying needs.

Moreover, mining companies have started to recognise the potential business opportunities of investing in low-carbon energy generation to supply electricity, besides their own operations, also to other customers. Traditionally, mining companies often found themselves in direct competition for scarce energy resources with local communities and other businesses, which has created additional pressures to secure and maintain their social licence to operate. Besides the economic interest for mining companies, the transition to renewable energy can generate wider social benefits, and contribute to the countries' achievement of the Sustainable Development Goals (SDGs), in particular, SDG 7 on affordable and clean energy and SDG 13 on climate action. These efforts may include the shared use of infrastructure with local communities and businesses, the diversification of mining companies' portfolios towards renewables, as well as participating in the value chains of innovative clean energy solutions, such as fuel cell technology.

Despite the existence of a business case and policy drivers for integrating renewables in mining and a growing number of successfully delivered projects worldwide, a decisive shift of the whole mining industry towards a low-emission business model is yet to take place. As a relatively new technology for mining companies, renewable energy may pose a number of operational and financial risks, coupled in some countries with policy-related factors, which may impede the accelerated uptake of green business practices throughout the industry. Furthermore, the energy transition of the mining sector needs to be accompanied by the increased electrification of operations, and the growth in the renewable energy sector for the mining industry to partner with.

Establishing an enabling policy environment is crucial to effectively promoting the synergies between the development of the mining and renewable energy sectors, and helping overcome remaining barriers. Drawing on the OECD *Framework for Extractive Projects on Collaborative Strategies for In-Country Shared Value Creation*, the analysis in this paper identifies a number of key areas requiring heightened attention:

Integrating the mining sector's changing energy needs into long-term national policies and mining companies' business strategies

In order to align the mining sector with the 2030 Sustainable Development Agenda and the objectives of the global energy transition, the sector's current and future energy demands should be well understood and explicitly reflected in national energy and mining policies. The ability to anticipate and manage long-term energy demands in a more efficient and cost-effective manner could be improved also at the individual company level. This would enable countries to anticipate, plan for, and adapt national infrastructure to potential changes in the sector's energy needs. This is particularly pertinent, in light of the growth of the clean technology industry, which is likely to increase demand for some rare earth elements, and other metals and minerals, leading in turn to the intensification of mining activities and associated energy requirements. It is equally crucial that the need for the energy transition is clearly embedded into mining companies' business strategies that would guide their performance in the coming decades, to ensure coherence with the changing international policy landscape.

Providing government support to bridge remaining risk gaps

Government support might be needed to help reach financial closure on innovative pilot projects that might otherwise not be implemented due to residual technological or financial risks, but have significant potential to generate benefits for the economy and society in the future. Continued innovation efforts are essential for overcoming the remaining barriers to scaling up the use of renewable energy solutions in mines and reducing their carbon footprint, ensuring the future sustainable development of the sector. International development finance is also important in bridging risk gaps, by protecting lenders against real or perceived commercial or political risks in developing countries, and building their investor confidence in renewable energy projects for the mining industry.

Determining a competitive domestic energy market structure

Another important factor in improving the uptake of renewables by the mining sector is a competitive structure of the domestic energy market. It should be conducive to the development of the renewable energy sector, and support the emergence of experienced and credit worthy renewable energy companies for the mining industry to partner with. An enabling energy market structure would also allow the sale of any excess power generated by mines to neighbouring communities or national grid. At the same time, along with liberalisation elements, the policy framework should integrate effective regulation, such as carbon pricing, in order to accelerate the energy transition at the lowest cost.

Ensuring adequate energy infrastructure to accommodate the expansion of the renewable energy sector

It is equally critical to ensure the existence of the necessary energy infrastructure, particularly transmission networks, to accommodate renewable energy expansion. While decentralised power generation is presenting a solution for remote off-grid mines, larger-scale solar and wind projects require a grid connection to ensure the off-take of excess power. The quality and size of the electricity grid, therefore, remains a key factor in driving the overall growth and competition in the renewable energy sector, including for the mining industry.

Reforming fossil fuel subsidies to further improve renewables' competitiveness

Energy subsidies continue to be one of the factors affecting the competitiveness of renewable energy, compared to fossil fuels. Government efforts seeking to promote the use of renewables by energy-intensive mining activities should, therefore, be considered in the broader policy context of incentives that may negatively affect the competitiveness of clean energy sources vis-à-vis fossil fuels.

Introduction

The current carbon-intensive model of economic growth, which has had a detrimental impact on the natural environment and climate, now poses a threat to the foundations and continuity of this growth itself. The scale of potential damages from the changing climate, coupled with broader environmental degradation and air pollution, poses a major risk to the future economic growth and development. This climate change risk is particularly high for low-income, less-resilient countries. The 2015 Paris Agreement and the 2030 Agenda for Sustainable Development clearly identify the urgency for the global economy to shift to a low-emission climate-resilient development pathway, to avoid costly effects of climate change for sustainable development, and adapt to the impacts that have already been locked in.

Resource-rich countries, in particular developing and emerging economies heavily reliant on their energy- and emission-intensive mining activities for economic growth, face a major challenge to maintaining their competitiveness in a low-carbon future. The mining sector is often associated with negative impact on the environment and climate, and surrounding local communities. The sector is also frequently viewed as operating in a silo, and disconnected from the rest of the economy.

At the same time, the mining sector has the potential to act as a catalyst for broad-based diversified economic development. Besides generating substantial government revenues, it can boost economic activity in various sectors, not limited to natural resources, spurring innovation and channelling investment to critical areas, such as infrastructure and technology, particularly relevant in the context of the global low-emission transition. Mining activities have a direct and indirect impact on meeting virtually all 17 Sustainable Development Goals (SDGs) (CCSI/UNDP/SDSN/WEF, 2016), in particular, the SDG 7 (affordable and clean energy), 9 (industry, innovation and infrastructure) and 13 (climate action). Importantly, the mining industry is at the start of green value chains, supplying minerals and metals for clean technology. The growth of the clean technology industry is likely to lead to a significant increase in mining activities. According to the World Bank’s estimates, meeting the objective of the Paris Agreement to limit the global warming to 2°C above pre-industrial levels would dramatically increase demand for certain minerals, such as aluminium, cobalt, iron, lead, lithium, manganese and nickel. Solar and wind technologies are likely to double the demand for these minerals, while manufacturing batteries would increase it by more than 1000% (World Bank, 2017).

While mineral demand is projected to increase driven by clean technology, it is vital to ensure that the mining sector itself undergoes a major transformation to reduce its environmental and carbon footprint. This paper seeks to contribute to shaping the sustainable future development of the mining sector, by exploring options for its timely energy transition, which would generate economic benefits for the industry itself as well as a positive change for society at large.

The paper has been developed under the Policy Dialogue on Natural Resource-based Development, hosted by the OECD Development Centre. Since 2013, the Policy Dialogue has offered a platform for peer learning and knowledge sharing where OECD and non-OECD natural resource-rich countries, all participating on an equal footing, have worked with extractive sector companies, civil society organisations, and research institutions, to craft innovative and collaborative solutions for resource-based development. In 2016, participants in the Policy Dialogue endorsed the *Framework for Extractive Projects on Collaborative Strategies for In-Country Shared Value Creation*, developed through an inclusive multi-stakeholder consultation process (OECD, 2016). The *Framework* contains key recommendations for governments and the industry on harnessing economic linkages between the extractive sector and the rest of the economy, including the shared use of energy infrastructure (*Framework's Step 3.1*) and technology innovation (*Framework's Step 4*) (see Annex).

As part of on-going work on the operationalisation of the recommendations contained in the *Framework*, the Eighth Plenary Meeting of the Policy Dialogue in June 2017 convened a discussion on the integration of renewable energy solutions in extractive operations. Participants discussed and validated for inclusion in the on-line Compendium of Practices – a companion tool for the *Framework* – a tranche of three case studies: grid-connected solar power plant in Collahuasi's copper mine in Chile (OECD Development Centre, Compendium of Practices, 2017a); off-grid solar solution to complement diesel power generation at Sandfire Resources' DeGrussa copper-gold mine in Australia (OECD Development Centre, Compendium of Practices, 2017b); and solar thermal solution for enhanced oil recovery by the Petroleum Development Oman (OECD Development Centre, Compendium of Practices, 2017c). This discussion identified a number of lessons learned, pointing to a variety of cost efficiency-related benefits, but also operational, financial and policy-related challenges, associated with the integration of renewables.

Through an analytical review of over 30 existing projects worldwide (Table 2.1), this paper presents an opportunity to deepen the understanding of the synergies between the development of countries' mining and renewable energy sectors. It focuses on exploring key drivers for, and obstacles to, renewable energy integration in mining, and possible approaches to accelerating this energy transition. The paper is structured as follows: Section 1 provides an account of the key factors contributing to the business case for renewables in mining, and main obstacles that persist; Section 2 offers an analysis of the existing business models, the associated challenges and emerging solutions. Section 3 concludes by providing policy recommendations to the governments seeking to promote the energy transition of their mining industry and the synergistic development of the domestic renewable energy sector, thereby contributing to the achievement of the SDGs and the objectives of the Paris Agreement.

1. Key drivers and risks for the integration of renewables in mining

As renewables have become an increasingly cost-competitive source of power generation, there is an emerging business case for the adoption of solar and wind energy solutions in the mining sector, cutting mines' energy costs, thereby reducing the industry's carbon footprint and generating wider positive social impacts. The integration of new technologies into pre-existing energy systems may, however, come with risks and challenges, which need to be recognised and addressed. This section provides an overview of key factors contributing to and impeding the uptake of renewables in mining operations.

1.1. Factors contributing to creating a business case for renewables in mining

Mining activities are energy-intensive, relying predominantly on fossil fuels

The mining sector is among top energy end-users, representing a significant share of resource-rich countries' final energy consumption (IEA, 2017a). As an example, in 2014, the mining and quarrying sector accounted for 38% of total electricity consumption in Chile and for 7.5% in Australia.[1] Fossil fuels remain a dominant source of energy for mining activities. Many resource-rich countries continue to rely on fossil fuels to power their industry, including grid-connected mines, with renewables representing a limited share in their economies' total energy consumption (Figure 1.1). At the same time, off-grid mines depend predominantly on diesel and gas to generate electricity. Besides electricity to supply operations such as grinding, electroextraction, conveyor transportation, ventilation and air conditioning, mines also use oil products – diesel or petrol – to fuel machinery and transport (Figure 1.2). Depending on the type of commodity and its extraction processes, heat can also be an important energy need, for example, in the electro-winning of metals from ores (Philibert, 2017).

Energy price volatility and supply quality deficiencies

The dependence on fossil fuels is fraught with significant uncertainties, given the price volatility that has traditionally characterised fossil fuel markets. In the past decade alone, the prices of crude oil and oil products saw a number of peaks. In 2008, prices reached an all-time high, followed by a fall, and another rise in 2011, remaining high until a new decline started in 2014, leading to record low prices in 2016. Given that energy costs can represent up to 30% of mining companies' operating costs (Soliman et al., 2017), this price volatility renders forecasting and planning relatively challenging, thereby posing cost-related risks for energy-intensive mining activities.

Besides the cost of energy, supply security is also an important business consideration for mining companies. Fossil fuel-based energy systems are often characterised by a

[1] Based on the IEA Energy Balance statistics.

degree of supply uncertainty, particularly in countries dependent on energy imports. For example, this was the case for Chile in 2007, when Argentina suspended its exports of natural gas (Box 3.1).

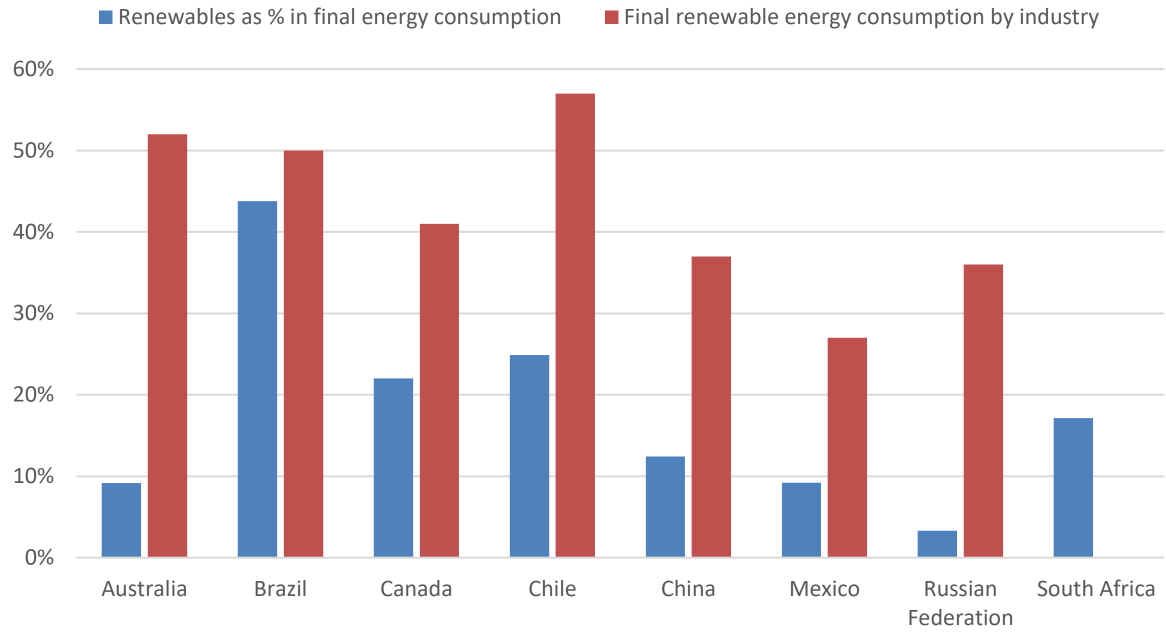
Many mines, especially in developing economies, and geographically dispersed and sparsely populated countries, may also suffer from energy infrastructure gaps and associated low-quality electricity supply. This may feature blackouts, load shedding, forced load curtailment or no access to the state grid. In view of these challenges, mining companies often find themselves in competition for scarce energy resources with local communities, which gives rise to discontent and weakens their social licence to operate (OECD, 2016).

As a result, mining companies have come under internal and external pressure to revisit their energy consumption patterns, to reduce energy-related supply and costs risks. Mines often start producing their own electricity through diesel or gas generators, in order to improve supply certainty. When there is an economic case, even grid-connected mines might resort to self-generation, to avoid supply disruptions, even if the price per unit of electricity generated is higher than that of the unstable supply from the grid. Between 2000 and 2012, mining companies across Africa invested USD 1.3 billion into around 1.6 GW power generation capacity, predominantly diesel and heavy fuel oil (HFO), under various self-supply arrangements (Banerjee et al., 2015).

However, even in case of self-generation, supply chain disruptions to fuel shipping and associated transport costs, particularly for remote mines in countries that face significant infrastructure gaps, can introduce further pressures in the timely and cost-efficient delivery of fuel. For example, diesel must be transported to Diavik mine in the Northwest Territories, Canada each year during a limited period over a temporary winter ice road, while to Raglan mine in the Nunavik region of northern Quebec diesel is shipped during a short marine season in summer.

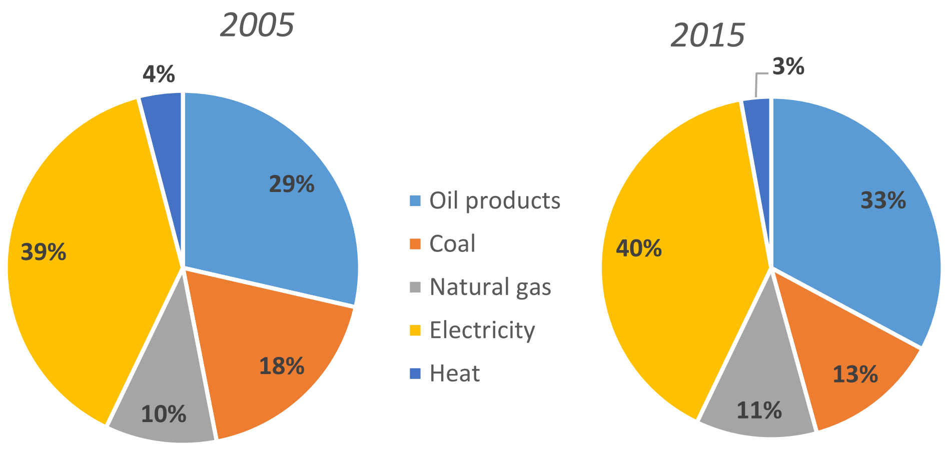
Efforts are also being made to improve efficiency and reduce the energy intensity of operations, including through the automation and digitalisation of operations. However, the sector's overall energy demand is likely to continue to grow, as it becomes increasingly harder and thus energy-intensive to extract commodities of declining ore grades and located deeper under-ground (EY, 2014; Rüttinger & Sharma, 2016). This calls for the adoption of new energy sources in the mining sector, which would meet the increasing energy demand, while reducing energy costs and improving supply security.

Figure 1.1. Renewable energy consumption of selected resource-rich countries, 2015



Source: Based on the data retrieved from the World Bank's Sustainable Energy for All database (on renewable energy as a share of total final energy consumption) (accessed 2 August 2018), and on the data retrieved from IRENA Renewable Energy Balances database (final renewable energy consumption by industry) (accessed 2 August 2018).

Figure 1.2. Energy consumption of the mining and quarrying sector by source, world



Note: The large majority of the heat included in this figure comes from the combustion of fuels, with small amounts produced from electrically powered heat pumps and boilers.

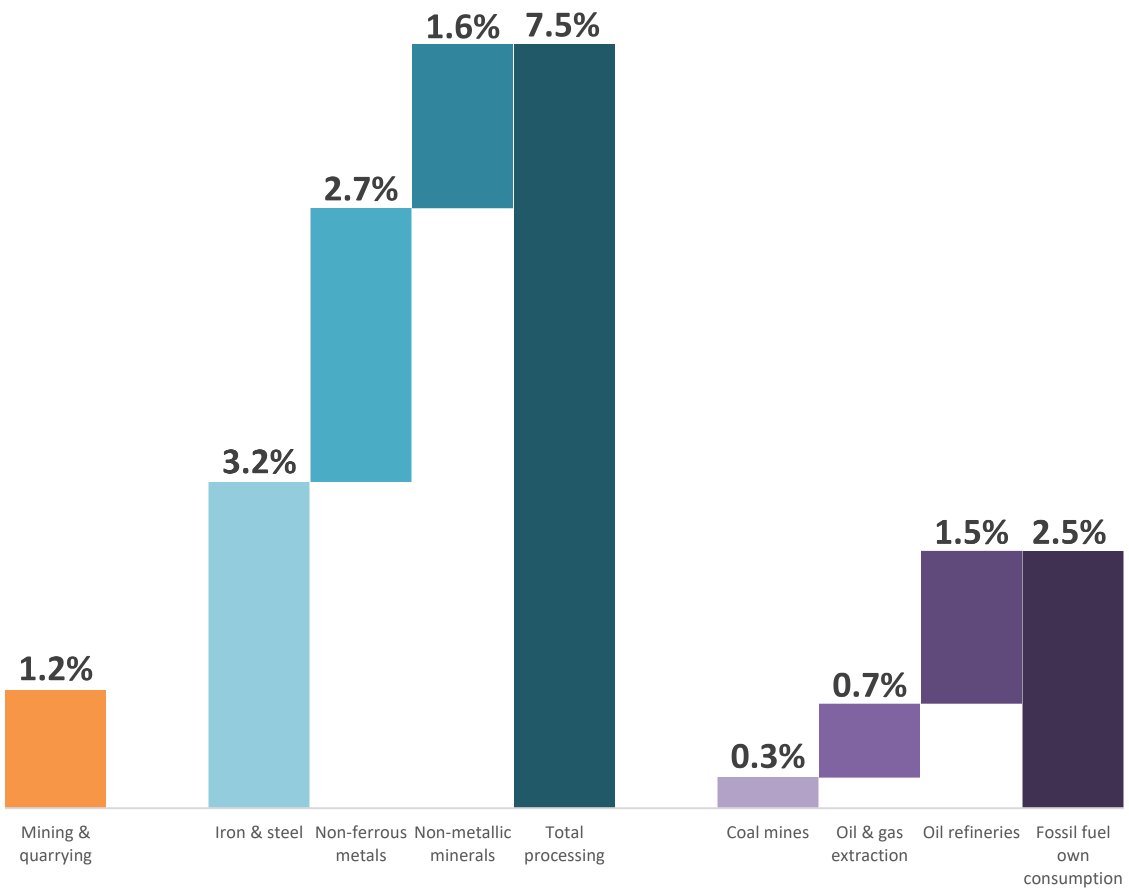
Source: Author, based on the IEA World Energy Balance data for OECD and over 100 other key energy consuming countries (accessed 2 April 2018).

Policy risks and pressures associated with emission intensity of mining operations

Given the reliance of mining activities on fossil fuels, the sector is among top greenhouse gas (GHG) emitters (IEA, 2017a). The mining sector is also at the start of some highly energy-intensive value chains. The fossil fuel-based energy sectors – oil, gas and coal – generate significant GHG emissions both upstream and downstream (Figure 1.3). By way of comparison, the downstream emissions from mining and metal industry, such as steel, iron or aluminium production, may be up to 30 times higher than the mining sector's own upstream operational emissions (Soliman et al., 2017). For example, the extraction of bauxite ore generates relatively low emissions compared to the electrolysis to aluminium, which is an extremely energy-intensive process (Schlösser et al., 2017).

Figure 1.3. Electricity and heat consumption by extractive sub-sectors

As a share of economies' total electricity and heat consumption, OECD, 2014



Source: Author, based on the IEA Energy Balance data (accessed 9 April 2018).

Energy and emission-intensity of mining activities and downstream processing operations expose the industry to potential policy risks. The changing global policy landscape, driven by the goals adopted under the Paris Agreement and the 2030 Agenda, has a wide range of implications for the mining sector. In order to meet these goals, governments increasingly seek to promote mitigation and adaptation practices, such as shifting to cleaner power generation and resilient infrastructure, increasing energy and water use efficiency, and improving sustainable land-use management. These efforts include, among others, regulatory measures, such as carbon pricing, that governments may introduce or tighten to constrain actions contributing to climate change (TCFD, 2017). An example is the recent roll-out of the national Emission Trading System (ETS) in China, which as its first step covers the coal and natural gas sectors (Timperley, 2018). These policy instruments are likely to put upward pressure on fossil fuel-based energy consumption, resulting in an important impact on operating costs of energy-intensive mining activities.

Related reputational risks can also be significant. There is evidence that stigmatisation of fossil fuel companies, triggered by public divestment campaigns, may increase business uncertainty and have a permanent negative impact on their valuation (Ansar et al., 2013). This, coupled with the mining industry's competition for scarce energy resources with local communities, may pose a significant social risk to the future smooth development of the industry.

As a result, mining companies have come under increasing pressure from their shareholders to disclose and act on climate-related physical, financial and transition risks, following the recommendations of the Financial Stability Board's Task Force on Climate-related Financial Disclosures (TCFD) adopted in 2015. For example, in its first climate scenario analysis released for its shareholders in 2015, BHP Billiton highlighted the company's relative resilience vis-à-vis climate-related risks, while noting that it might still lose up to 5% of its portfolio value, should the government raise the carbon price to USD 80 per tonne of CO_2 (BHP Billiton, 2015).

Furthermore, downstream customers, particularly the green technology industry, exert increasing pressure on the mining industry to reduce emissions. These companies seek to decrease the overall carbon footprint of their final products. They therefore focus on the emission intensity of the minerals and metals' extraction required in the clean technologies they manufacture. An example is the Responsible Copper Initiative by the Chilean state-owned copper producer Codelco and the German BMW Group. The initiative aims to minimise the environmental impact of increased demand for copper, driven by the production of electric vehicles (BMW Group, 2018).

Declining cost of technology offers an opportunity for the integration of renewables in mining and improving energy access for local communities

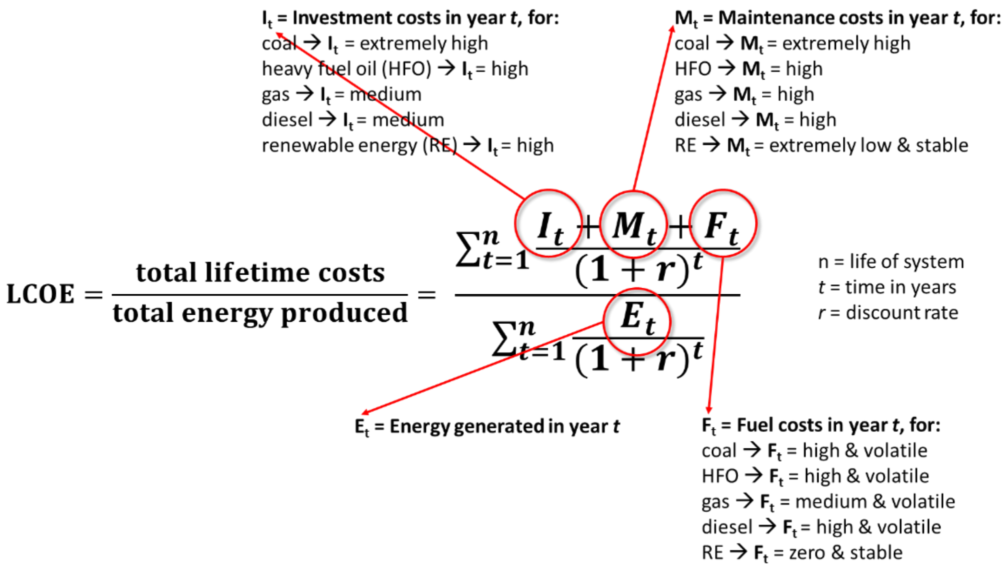
In the context of fossil fuel price volatility, supply uncertainties, and potentially significant policy and regulatory risks, clean power generation has become increasingly competitive and attractive for the mining sector (IEA, 2017b).[2] Renewable energy technologies have seen a rapid decline in costs over the past years. Since 2010, the costs of solar photovoltaics (PV) have decreased by 70%, and wind power technology by 25%. As a result, the deployment of renewables has increased considerably, particularly of solar PV, which in 2016 outstripped the growth in any other form of new power generation, with renewables reaching nearly a quarter in the world's electricity generation (IEA, 2017b).

Low-carbon power has the potential to provide price stability and cost savings, in particular for new projects with high renewable energy fractions. Based on estimates, improved energy management through the scaled-up use of renewables can reduce mining companies' energy costs by 25% for existing operations and up to 50% for new mines (Deloitte, 2017). Before a mining company starts considering the integration of

[2] This paper focuses mostly on renewable energy solutions for mining activities. There is scope for further research to look at issues related to the energy transition of processing facilities (Section 3.2).

solar or wind power into its energy mix, it is important to reach clarity on the levelised cost of energy of a specific mine – lifetime energy costs divided by total energy produced. The levelised cost may depend on a number of factors, such as investment, maintenance and fuel costs, as well as the overall energy production and life of the system. Capital and operating costs vary significantly, depending on the source of energy (Figure 1.4). For example, in comparison to fossil fuels, the development of a renewable energy plant involves high upfront capital costs, but relatively lower maintenance and zero fuel costs. At the same time, fossil fuel-based energy systems incur relatively higher operating costs, driven by volatile fuel prices, as discussed above, which are however spread over the whole lifetime of the asset.

Figure 1.4. Composition of mines' levelised cost of electricity



Source: Adapted from Cronimet Mining Power Solutions presentation, Tenth Plenary Meeting of the Policy Dialogue on Natural Resource-based Development, 25 June 2018, Paris, www.oecd.org/dev/tenth-meeting-pd-nr-june-2018.htm.

Advancements in energy storage technologies have also contributed to strengthening the business case of renewables for mines. Innovation in the battery industry has created viable solutions to the challenges related to the variability of renewable energy output, which depends on weather conditions. The improvement in the penetration ratios of renewables to fossil fuels, coupled with a 40% cost reduction in battery technologies since 2010 (IEA, 2017b), have further increased the attractiveness of renewable energy sources for mines. The experience from the implementation of renewable energy and storage projects, such as at DeGrussa and Weipa mines (Box 3.2), is expected to contribute to an improved understanding of renewable energy application in industrial use. Furthermore, the digital transformation of the mining sector, such as the adoption of smart grids and other internet of things-based technologies, and the use of advanced analytics and big data, have the potential to further improve mines' energy efficiency and facilitate the integration of renewables.

As a result, to hedge risks and reduce costs associated with their energy consumption, mining companies have increasingly started to consider renewable energy sources to complement their fossil fuel-based energy mix. According to estimates, there is currently over 1 GW of on- and off-grid renewable energy capacity, installed through mining companies' efforts, with more projects in the pipeline (Energy and Mines, 2016a). Although renewables may currently have a minor role in the electricity consumption of the global mining industry (estimated at 0.1-0.2%), their share is projected to rise to 5-8% by 2022 (Navigant Research, 2013).

Renewable energy solutions also provide an important opportunity for mines to enter the electricity generation market, and sell any excess power to other consumers, for example, nearby local communities through mini-grid arrangements, or to the national grid, in the case of grid-connected mines (Section 2.3). Renewable electricity production can allow mining companies to generate supplementary revenues, in addition to their core business, and strengthen their social licence with surrounding communities.

Moreover, the integration of renewable energy solutions to power the mining sector may present an opportunity for resource-rich countries to develop their domestic renewable energy industry, in turn creating a growing market for the minerals they produce. Clean energy technologies, requiring a number of minerals and metals, involve high value-added manufacturing and innovation activities, with the potential to drive the development of the necessary skill base and the auxiliary service sector (OECD/UN, 2018).The synergistic development of the two sectors may therefore create important growth opportunities for resource-rich economies.

1.2. Operational and financial risks related to mines' energy transition

As a relatively new technology for mining companies, the integration of solar or wind power into pre-existing fossil fuel-based set-ups may create a number of bottlenecks at the design and installation phase. The variability of wind and solar energy supply requires further adjustments to current power systems to ensure grid stability – the deployment of energy storage solutions and integrated control tools to effectively manage multi-source hybrid power structures. Mining companies also often lack the required technical expertise and capacity to integrate and run renewable power systems on their sites, which may lead to reluctance and delays in adopting the new energy solutions already available.

The integration of renewables in mining also sometimes requires a degree of technological and design innovation to adapt to unique natural conditions of specific sites. For example, extreme negative temperatures at Glencore's Raglan mine in northern Quebec, Canada meant that the development of a wind power and storage project had to be completed in record time, during a short Arctic summer. The Atacama Desert in Chile faces an opposite challenge: solar radiation is so high there that cables in solar power plants need to be replaced every six months or require more resistant insulation to protect them from being burnt (Miroff, 2017). Loose desert sediments and dust deposition may pose a further challenge to the operation of renewable energy plants (Olivares et al., 2016). At the same time, a wind power plant at Barrick Gold's Veladero mine in Argentina was built in the challenging conditions of an elevation of 4 300 metres. The key issues faced by the developer included relatively lower wind yields, as a result of reduced air density, and reliability of electric components at high altitude. The logistical challenges of transporting the turbine to the mine also had to be overcome (DeWind, 2018).

Furthermore, the future energy transition of the mining sector will depend on the pace of electrification of operations, such as digging and haulage. In the past decade the share of electricity in the total energy consumption mix of the global mining sector has remained relatively stable (Figure 1.2). This signals the need for scaled up electrification, should renewables take a greater share in the overall energy mix of mining operations. While some individual examples of using electric excavators and battery-powered vans in mines have emerged in the past years, the shift of the entire sector is likely to take time, in turn slowing down the integration of renewables in mining (Rycroft, 2017).

Besides operational risks, investment in renewable energy assets incurs high upfront capital expenditure, often requiring debt financing. This may discourage mining companies that would rather invest their capital into the core business (Section 2.1). Reaching financial closure on renewable energy projects, even those that are developed and owned by an independent power producer (IPP), is also often fraught with challenges, given a number of risks faced by the developer and financer, such as creditworthiness of a mine, as an off-taker or developers' credit rating (Section 2.2).

Various approaches are emerging to address some of the challenges at the operational, financial and policy level. Section 2 will review a wide array of existing projects and their business models, financing structures and design, to determine their relative advantages and limitations. Government support is often needed to bridge the gap between innovation and commercialisation, and help overcome operational and financial risks faced by cutting-edge projects. An enabling policy environment is important for the development of a strong and competitive renewable energy sector to supply both industrial and domestic consumers. Section 3 identifies key enabling policy factors required for the replicability and accelerated uptake of the available renewable energy solutions throughout the mining sector.

2. Review of business models: Risks and possible solutions

There is a clear trend that mining companies are increasingly recognising the opportunities presented by the wind and solar potential of the locations where they operate to power their extractive activities. Major companies and conglomerates, among others, such as Glencore, Barrick Gold, Rio Tinto, Antofagasta, Codelco and IAMGOLD have all made use of renewable energy in their mines (Table 2.1). There seems to be a relative balance between solar PV and wind power, with solar thermal projects remaining scarce.

Latin America, particularly Chile (Box 3.1) and Mexico, is leading the way in utility-scale projects. Notable examples of large plants are Antofagasta's 115 MW wind power and CAP's 100 MW solar PV projects in Chile, as well as Industrias Penoles' 180 MW wind power plant in Mexico. Among smaller initiatives, the geographical distribution is more diverse, with Australia and Canada, as well as South Africa, emerging as potential hubs. At the same time, in developing countries, particularly in lower-income economies, despite the existence of some successful projects, the uptake of renewables by mines remains limited.

Various business models are emerging to integrate renewable energy solutions within mining operations. A review of the existing approaches demonstrates the prevalence of two main financing structures: a self-generation model, where a mine owns its renewable energy plant, and a model involving a power purchase agreement (PPA), whereby a mine purchases renewable energy from an independent power producer (IPP). However, both options are fraught with model-specific challenges, and therefore in the recent years alternative innovative business arrangements have emerged, such as rental and re-deployable solutions. This section explores the relative strengths and shortcomings of different models, as well as new business opportunities arising for mining companies in the low-carbon energy sector.

2.1. The self-generation model and associated challenges

When it makes economic sense for a mine to own its renewable energy plant, the mining company might opt to finance, develop and operate a plant on the mining site. For example, Galaxy Resources' Mt Cattlin lithium mine was the first mine site in Australia to install solar in 2011, aiming to complement its 5 MW diesel generator. In addition, Galaxy Resources installed two wind turbines, which together with solar generates 225 MWh per year of renewable energy and saves annually up to 200 tonnes of CO_2 emissions (Galaxy Resources, 2018). Another example where a mining company assumes direct ownership over a renewable energy power plant is Cronimet RSA, a German-owned South African chromium ore mining company that installed a solar-diesel hybrid system on its land at Thabazimbi mine in Limpopo. Cronimet completed and now operates the 1 MW solar project through a PPA arrangement with its holding company Cronimet Mining-Power Solutions (Boyse et al., 2014). When the plant was commissioned in 2012, the price per kWh offered by the PPA was 23% lower than the electricity cost per unit generated from diesel (Cronimet, 2018a).

While the self-generation model tends to be often chosen by off-grid mines, a wind project in Nouadhibou, Mauritania, offers an example of a self-financed grid-connected wind project built to supply the operations of the state-owned iron ore mining company, Société Nationale Industrielle et Minière (SNIM). The project, worth EUR 7.8 million, was financed entirely using SNIM's own equity (SNIM, 2012). The hybrid wind-diesel system has renewable energy capacity of about 4.5 MW, with an average penetration rate between 30% and 50% at peak times (Vergnet, 2018).

Table 2.1. Examples of renewable energy projects in mines worldwide

Mining company	Mine/Project	RE partner	Financing	Grid connection	Country	RE capacity (MW)	RE technology
Cronimet Mining AG	Thabazimbi	Cronimet Power Solutions	Self-generation	Off	South Africa	1	Solar PV
Barrick Gold	McCarran	Stellar Energy	Self-generation	Off	United States	1.51	Solar PV
B2Gold	Otjikoto	Caterpillar	Self-generation	Off	Namibia	7	Solar PV
SNIM	Nouadhibou	Atersa PV	Self-generation	On	Mauritania	3	Solar PV
Antofagasta Minerals	El Tesoro	Soitec Solar	Self-generation	Off	Chile	0.06	Concentrated PV
Özkoyuncu Mining		Hanwha SolarOne and Else Enerji	Self-generation	On	Turkey	2	Solar PV
Galaxy Resources	Mt Cattlin	Swan Energy	Self-generation	Off	Australia	0.11/0.06	Solar PV/Wind
Rio Tinto /Dominion Diamond Corporation	Diavik Diamond	ENERCON Canada	Self-generation	Off	Canada	9.2	Wind
SNIM	Nouadhibou	Vergnet	Self-generation	On	Mauritania	4.5	Wind
Grupo Mexico	El Retiro wind farm	Gamesa	Self-generation	On	Mexico	74	Wind
Nyrstar	El Toqui	Vergnet	Self-generation	Off	Chile	1.5/2.3	Wind/Hydro
Gold Fields	South Deep		PPA	On	South Africa	40	Solar PV
Imagold	Rosebel	RERC	PPA	On	Suriname	5	Solar PV
Antofagasta Minerals	Chuquicamata	Solarpack	PPA	On	Chile	1	Solar PV
Minera Dayton	Andacollo	Solairedirect	PPA	On	Chile	1.26	Solar PV
CAP Group	Copiapo	Sunedison	PPA	On	Chile	100	Solar PV

Antofagasta Minerals	Conejo Solar for Los Pelambres mine	Pattern Energy	PPA	On	Chile	122	Solar PV
Collahuasi	Collahuasi	Solarpack	PPA	On	Chile	25	Solar PV
Quiborax	El Aguila Punta	E-CL	PPA	On	Chile	2.3	Solar PV
Iamgold	Essakane	Total Eren	PPA	Off	Burkina Faso	15	Solar PV
Rio Tinto	Weipa	First Solar	PPA	Off	Australia	1.7	Solar PV + storage
Sandfire Resources	Degrussa	Neoen	PPA	Off	Australia	10.6	Solar PV + storage
Antofagasta Minerals	El Tesoro	Abengoa	PPA	On	Chile	10.5	CSP
Antofagasta Minerals	Los Pelambres	Pattern Energy	PPA	On	Chile	115	Wind
Barrick Gold	Punta Colorada	Rame Energy	PPA	On	Chile	20	Wind
Mandalay Resources	Cerro Bayo	Rame Energy	PPA	Off	Chile	1.8	Wind
Industrias Penoles		Electricidad de Portugal Renovables	PPA	On	Mexico	180	Wind
Glencore	Raglan	Tugliq Energy	PPA	Off	Canada	3	Wind + storage
Barrick Gold	Veladero	Rame Energy	PPA	Off	Argentina	2	Wind
Codelco	Gabriela Mistral	Pampa Elvira Solar	Heat Purchase Agreement		Chile	27.5	Solar thermal
Shanta Gold	New Luika	Redavia Solar	Rental	Off	Tanzania	0.67	Solar PV

Note: Without being exhaustive, the table seeks to capture key known projects for which information is publicly available, and provides an overview of the extent to which renewables have penetrated the energy mix of the mining sector.

High up-front investment costs and capacity constraints pose a challenge to scaling up renewables

Investment in renewable energy effectively constitutes a shift for a mine from operating to capital expenditure, given the fixed nature of the underlying asset, high capital and relatively lower operating costs (ARENA, 2017). At the same time, obtaining fossil fuel-based generation assets is usually classified as operating expenditure,[3] characterised by limited upfront capital investment, and higher future fuel and maintenance costs (Figure 1.4). Mining companies may be resistant to this transition, given that it requires capitalisation on the balance sheet, and the recording of associated liabilities. Power generation is not mining companies' core business, and they may, therefore, prefer allocating capital to exploration or building new mines, rather than a power plant, even if it has the potential to generate cost savings over the medium term (Cullinen, 2015).

Mines deciding to build a renewable energy plant, usually seek debt-financing to fund this infrastructure investment. The terms of the financing would depend on the mining company's creditworthiness. Therefore, in order to obtain advantageous terms and bring down the interest rates, mines may choose to rely on their parent company's assets. This was the case for Cronimet that was successful through its German-based parent company in securing a USD 2.8 million loan from the Global Climate Partnership Fund (GCPF), an investment facility created by KfW – the German National Development Bank (GCPF, 2017; 2016). Thanks to these attractive financials, and the solar penetration rate that replaces 30% of mine's diesel consumption and generates significant annual fuel savings of 450 000 litres, the plant has an estimated 3.6 years payback time (GIZ/SAIIA, 2014). Mines that do not have a sufficiently strong credit rating or a parent company they can get support from, may find it difficult and costly to secure a loan.

Another factor which may reduce attractiveness of renewable energy for mining companies is the uncertainty about mines' remaining operating lifetime, which besides their productive life, also depends on the global commodity demand and prices. Sudden changes in market conditions may render mining of a specific mineral in particular location no longer economically viable. As a result, investment into long-term fixed capital assets, such as solar or wind power plants, may be risky for mines with short or uncertain operating time horizons, increasing their levelised cost of energy. This challenge is not unique to self-generation approach and is common also to PPA models (Section 2.2).

Investment into renewables may also be constrained by often limited technical capacity and first-hand experience of mining companies in using new technology (ARENA, 2017). Hybrid systems tend to be more complex in design and maintenance than common rooftop solar or utility-scale systems (Boyse et al., 2014). It is particularly challenging to integrate new technology into an existing power system (Section 1.2). However, even after hybrid setups have been installed by an expert project developer, maintenance often needs to be outsourced (Cullinen, 2015). This problem becomes more severe in isolated rural locations, where the lack of on-site technical capability to make quick repairs cannot be readily addressed through outsourcing. The experience of Sandfire Resources' project at the remote DeGrussa's mine has demonstrated the difficulties associated with integrating solar PV and energy storage technology into a diesel system. The co-ordination of several actors involved in the design, development

[3] The new International Financial Reporting Standards on leases (IFRS 16) may introduce changes to this classification (ARENA, 2017).

and maintenance of the hybrid system created an additional challenge (OECD Development Centre, Compendium of Practices, 2017b). Therefore, an important factor in improving the uptake of renewables is to strengthen electrical engineering skills within individual mines, in parallel with developing the service sector which mining companies could contract for design and maintenance functions (Boyse et al., 2014).

In view of these challenges, while some mining companies may have used the self-generation model, the scaling up of the adoption of renewable energy technology is likely to require alternative business models. There is a need for solutions that would eliminate the risks associated with costly upfront capital investments and the lack of technical expertise in the maintenance of assets (Cullinen, 2015).

2.2. The "renewables-as-a-service" model and its limitations

Power purchase agreements offer a solution to high up-front capital investments

Purchasing renewable energy from an IPP is becoming increasingly popular, with over half of the current solar and wind projects for mines operating on the basis of a corporate PPA. In comparison to a traditional PPA, where the off-taker is a utility, under corporate PPAs, the power generated is purchased, directly from a renewable energy producer, by corporate actors such as mining companies. Under this model, the mine as a corporate customer strikes a PPA with an IPP. The latter finances, develops and owns a power plant, usually on the mining site, and sells the electricity generated to the mine, which acts as an off-taker. As a result, given that renewable energy is effectively provided as a service, it allows a transfer of the capital investment from the mine's balance sheet to operating expenditure.

The price of electricity under a PPA is determined by the IPP's levelised cost of energy or the cost required to recoup the investment over the duration of the PPA. It usually comprises installed capital costs, plant operating expenses and IPP's cost of capital. The length of the PPA tends to be tied to the remaining lifespan of the mine. As discussed below in further detail, this is due to the limited re-deployability of current renewable energy systems, and the unexploited opportunities for plants' alternative uses, beyond the needs of a mine. Therefore, the longer the residual life of the mine, the longer the PPA, and thus the lower the price of the electricity generated under the contract.

A notable example is an innovative 3 MW wind power plant in Glencore's Raglan mine in northern Quebec, Canada, owned by Tugliq, an IPP specialising in remote hybrid off-grid energy solutions. Tugliq sells the electricity generated under a long-term PPA to Glencore. Operating in severe climatic conditions of up to –40 °C, the project is a first-of-its-kind, and was completed in a record time within a short Arctic summer. It costs nearly CAD 19 million, with a front-end engineering design (FEED) study worth further CAD 2 million (NRCan, 2016a; 2016b). To fund its Research and Development (R&D) component and FEED study, the project received a total grant of CAD 8.5 million from the ecoENERGY Innovation Initiative (ecoEII) (NRCan, 2016a). The energy system installed combines cutting-edge wind power generation technology and advanced controller with flywheel, lithium-ion battery and a hydrogen-based smart grid storage system to enable higher renewable energy penetration into the autonomous diesel-based micro-grid. The project constitutes a pilot, aiming to demonstrate feasibility and reliability of innovative wind-diesel hybrid systems, equipped with storage, to deliver significant reduction in fuel consumption and energy costs. Under this setup, reliance on fossil fuels would be reduced over time, and eventually eliminated, as penetration up to 100% is being tested in the future (Tugliq Energy, 2016). The project has already demonstrated a wind energy penetration rate of over 40%, and total annual fuel savings are estimated at 2.4 million litres (NRCan, 2016a).

The 115 MW El Arrayán wind power plant in Chile offers an important example of a large-scale project, developed through a joint venture of Pattern Energy (70%), a renewable energy producer, and Antofagasta Minerals, a Chilean mining company (30%). The joint venture partners signed a 20-year PPA with Minera Los Pelambres, a subsidiary of Antofagasta, which committed to offtake around 70% of the power generated. The rest is sold on the Chilean spot market. Siemens manufactured and installed 50 wind turbines, 2.3 MW each, and has provided the maintenance service. At the time of its completion in 2014, it was the largest wind power plant in Chile, saving over 300 000 tonnes of CO_2 per year (Pattern Energy, 2014).

Compared to wind and solar PV projects, the use of solar thermal energy to meet mines' heat demand remains limited (Table 2.1). A remarkable example is a solar thermal installation at Codelco's Gabriela Mistral mine in the Atacama region in the North of Chile. When it was completed in 2013, it was the largest thermo-solar plant in the world, generating 54 000 MWh per year. The plant is operated by Pampa Elvira Solar, a consortium between a Chilean company Energía Llaima and a Danish company Arcon-Sunmark, through a 10-year thermal PPA. The project replaces 85% of fossil fuels, generating annual diesel savings of 6 500 tonnes, and a 15 000 tonne reduction in CO_2 emissions per year. Furthermore, the plant eliminates the need for 250 haulage trucks, which would have been required to transport diesel to the mining site (Energía Llaima, 2018; ICMM, 2018). Chile seeks to further expand the use of solar thermal energy by its copper industry. For example, the Centre for Solar Energy Technologies – a joint initiative between the German Fraunhofer Institute for Solar Energy Systems and the Catholic University of Santiago – focuses its R&D activities on exploring, among others, the application of solar heat in mining (OECD, 2016; FCR-CSET, 2018).

Corporate PPAs are associated with bankability risks

A common source of financing for PPA-based renewable energy initiatives is project finance, where funding comes from debt or a debt-like source, e.g. third-party equity. The debt is then re-paid from the cash flow generated by the project. In order for lenders to agree to provide project finance, the debt should be bankable, meaning that it should have a sufficiently attractive risk profile, from both the off-taker's and developer's point of view.

Corporate PPAs are usually considered an important mechanism for increasing the pool of potential off-takers, and thereby contributing to the growth of the renewable energy sector. However, before a project reaches financial closure, there are a number of risks that all parties – mine, renewable energy company and lender – would need to give careful consideration to.

Credit worthiness of the mine as an off-taker

The credit rating of a mining company is an important factor for developers in creating a bankable PPA that is attractive to a potential financer. Lenders usually conduct thorough credit assessments before taking a decision to finance a project. Mines that are not sufficiently creditworthy to strike a PPA, particularly those in developing countries, may be required to provide credit enhancement, for example, in the form of a default guarantee from their parent company. The guarantee helps mitigate the risks faced by a bank that provides financing to their IPP, and thereby reduces a price offered by the PPA (Baker & McKenzie, 2015).

One of the emerging innovative financing solutions is an “energy for commodity” swap agreement. For example, Cronimet offers its mining clients an option to fund the off-take of electricity through commodities they extract rather than a cash settlement. This arrangement allows combining commodity trade finance, through Cronimet’s Trading division, with a PPA from Cronimet’s Power division. In addition to eliminating the need for upfront capital investment and risks associated with asset ownership for the mine, such a model provides a hedge against currency risks, which may also negatively affect project financing costs (Boyse et al., 2014; Cronimet, 2018b).

Mismatch between remaining mine life and asset life of a renewable power plant

While PPAs can alleviate some of the risks associated with the self-generation model, mining companies sometimes struggle to strike an agreement with an IPP of an optimal length. Due to uncertainties around the remaining operating lifetime of some mines (Section 2.1), a typical preferred length of an electricity contract may be relatively shorter than the time required by a developer to achieve payback on a renewable energy asset. Therefore, mines may opt for shorter PPAs of 5-15 years. At the same time, a typical solar or wind system tends to get amortised over a period of 25-30 years (ARENA, 2017). As a result, the annual capital repayments, which represent the majority of the lifetime costs of a renewable energy plant, when spread over a shorter term of a PPA, would be significantly higher than when spread across the longer potential operating horizon of the asset.

A logical approach would be to decouple the asset life of a renewable energy plant from the length of the first off-take agreement, which is in turn tied to the remaining operating lifecycle of a mine. This can be done by redeploying the renewable energy asset elsewhere, upon the closure of the mine. However, relocation of solar and wind system is often uneconomical, given high disassembly, transport and re-assembly costs, besides the cost of the technology itself. The risk of stranding the renewable energy assets, due to their limited re-deployability, may therefore create a barrier to their increased uptake in mining activities (ARENA, 2017).

By contrast, fossil fuel generators tend to have greater operational flexibility, and can be moved to a new location, after the mine reaches the end of its lifecycle. Therefore, while also having a long total lifespan of an average of 20 years, the operating time of a fossil fuel generator can be spread across multiple shorter phases, making them sometimes better aligned to the needs of the mining sector (ARENA, 2017).

As a result, while renewables may be able to generate electricity at a relatively low cost, the temporal misalignment may limit their competitiveness vis-à-vis fossil fuel generators. As discussed above, the length of a PPA is an important factor in striking an optimal contract, being one of the key determinants of the electricity off-take price. While shorter PPAs may still succeed in securing a lender, the cost and level of debt may be negatively affected by the limited duration of the PPA.

Developers’ credit rating and experience

The long-term creditworthiness of an IPP is also an important factor in bringing a project to a financial close. There is a default risk that the IPP can become insolvent, being unable to supply power to the off-taker and repay its debt to the lender. Mining companies and lenders are, therefore, more likely to partner with an experienced IPP that has strong ties to the investment community and is able to bring the project to financial closure. When looking across the array of current projects (Table 2.1), several of them, and particularly large-scale costly projects, involve well-established renewable energy developers (PWC, 2017).

Many countries have a fragmented renewable energy market, characterised by relatively small developers, with limited market power and modest financial position, unable to raise finance for costly capital-intensive projects. As an example, Valhalla, a Chilean renewable energy start-up has faced difficulties in securing USD 500 million financing required for its innovative Espejo de Tarapacá project in northern Chile. The planned costly 300 MW pump hydro plant would constitute a large electricity storage system using the natural advantage of the site – steep coastal cliffs where seawater can be pumped up during the day using abundant and cheap solar power, and stored in natural surface concavities, to release energy at night. The system can be complemented by a 600 MW Cielos de Tarapacá solar PV plant, costing further USD 600 million (Valhalla, 2018).

Another example of an IPP that faced financial challenges is Rame Energy, a UK-based renewable energy company focused on the Latin American market. The company developed wind power projects for Mandalay Resources in Chile and Barrick Gold in both Chile and Argentina. However, in 2016, Rame Energy went into administration with outstanding debt of GBP 4.4 million. Financial difficulties started after the company failed to raise GBP 2.8 million through private placing to fund its 210 MW portfolio of renewable energy assets (Azzopardi, 2016). Rame Energy explained the situation by siting adverse market conditions, following the 2016 United Kingdom European Union membership referendum. An agreement was reached to sell Rame Energy's share in Seawind Holding SpA and its subsidiaries in Chile to TUDA SPRL and Safe Harbour Capital (ADVFN, 2016).

Solutions are emerging to address existing challenges

Increased mobility through re-deployable or rental renewable energy solutions

To improve the re-deployability of renewable energy systems, efforts are being made to de-couple the life of a renewable power asset from the length of the first offtake agreement. For example, SunSHIFT, an Australian manufacturer of innovative solar systems, has started producing fully re-deployable pre-fabricated solar plants for on-grid and off-grid sites (ARENA, 2017). SunSHIFT explicitly aims to improve the integration of renewable energy in mines, by overcoming the challenges faced by traditional solar PV systems (Box 2.1). Similarly, UK-based Lightsource BP has adopted a flexible approach, offering its customers shorter solar PPAs of 5 to 10 years, and re-deploying the energy systems elsewhere, when the agreements are not extended (Golubova, 2016).

Rental solutions also provide the option of mitigating the risks associated with the self-generation model, as well as addressing the issue of mines' short or uncertain remaining operating horizons. For example, Redavia is a German-based company specialising in rental solar power solutions for corporate clients and communities. Its innovative business model allows its customers to rent solar PV plants for a fixed monthly fee on a short-term extendable contractual basis. In return, Redavia covers the upfront capital costs, supplies engineering and technology, preserving ownership over solar PV generation and storage systems (USAID, 2018). In its recent project in Tanzania, Redavia worked with Shanta Gold to install solar PV capacity within its diesel power generation system in the New Luika mine. The project started with a pilot of 63 kW in 2014, expanding it to a capacity of 674 kW in mid-2017. The hybrid solar-diesel solution now has the potential to save 219 000 litres of fuel annually, equivalent to 660 tonnes of CO_2 (Redavia, 2018).

Box 2.1. SunSHIFT's re-deployable solar PV systems

SunSHIFT, a subsidiary of Laing O'Rourke Australia, is a company engineering turnkey modular re-deployable solar systems. The mobile and flexible design of SunSHIFT technology reduces on-site assembly costs and allows the re-deployment of energy systems on other sites. The individual pre-fabricated 2kW PV modules can be assembled into 50kW arrays and 1 MW blocks, and in turn combined into systems of any desired capacity. The energy systems can also be gradually expanded, and complemented by storage technology, or easily disassembled for re-deployment elsewhere. This arrangement minimises the need for local labour and equipment, which is an important benefit in remote locations with limited technical capacity. SunSHIFT technology, which can be purchased, rented or made available through a PPA, is able to support shorter contract terms, often favoured by mines with uncertain life horizons. The mobile nature of these PV systems also allows the use of asset financing as opposed to project financing.

The initiative was supported by the Australian Renewable Energy Agency (ARENA), which provided AUD 410 000 for feasibility and design work, and contributed a quarter of the AUD 1.8 million demonstration project's value. Among the first projects to use SunSHIFT technology is the South32's Cannington mine in Queensland, Australia. It integrates 3 MW solar PV into an existing gas power plant and is independently funded by South32.

Source: ARENA (2017), *Renewable Energy in the Australian Mining Sector – White Paper*; ARENA (2016a), "Moveable solar power shifts closer to commercial reality"; Djordjevic, M. (2018), "Solar to power Cannington mine"; and South32 (2018), "Solar to power Cannington mine".

Shorter payback periods thanks to improved design and technology

Recent experience has also shown that payback periods on renewable energy investments in mining projects need not be unaffordably long. As technology improves and industry's experience increases, shorter payback periods can be achieved through better renewable energy penetration, reduced fuel consumption and greater energy cost savings. For example, real-time solar tracking panels used by Galaxy Resources' solar power plant in the lithium mine in Australia are able to follow the sun from the east to the west, generating 15% more electricity than a conventional solar PV installation (Galaxy Resources, 2018).

Another important technology used in hybrid power plants is the controller and grid stabilisation system that supports the integration of combined set-ups and allows the management of the flow of electricity generated by different sources, either fossil fuels or renewable energy. ABB's Renewable Microgrid Controller (MGC600) integrates different power generation sources into a combined, usually isolated off-grid, but also grid-connected, system. The MGC600 was used in Nyrstar's El Toqui mine in Chile, for its hybrid wind, hydro and diesel power plant, in order to improve the stability of the micro-grid system. Without the controller, fluctuations in wind power outputs caused stability issues, resulting in the occasional need for turning off the wind turbines, thereby increasing fuel consumption. In combination with PowerStore grid stabilisation system, the MGC600 was able to manage the hybrid energy system, delivering a 29% increase in energy yield, by maximising renewable energy penetration (ABB, 2018).

A Caterpillar micro-grid master controller (MMC), which functions in a similar manner, monitoring performance of an integrated hybrid power plant while collecting data for further analysis, has been installed in the solar power plant at the B2Gold's Otjikoto mine in Namibia (Mccloy, 2017). The 7 MW project has an estimated payback period of 4.3 years. Similarly, the success of the solar PV plant at Cronimet's Thabazimbi mine in South Africa, with its payback period of less than four years, is attributed, aside from financial factors, to the use of a programmable logic control (PLC) system that helps achieve the solar penetration ratio of 60% (Boyse et al., 2014; Judd, 2018).

Industrial pooling for greater combined demand and economies of scale

Compared to a load serving utility, a single mine is likely to have a less certain energy demand, which sometimes results in difficulties in securing a lender for a project or an IPP. In light of this, a reduction in costs can be attained by an industrial pooling arrangement (combining energy demands with other mines or companies), in order to achieve greater economy of scale (*Framework's* Step 3.2.1.B.vi*;* see Annex).

This was the rationale behind the South Australian Chamber of Mines and Energy (SACOME)'s decision to obtain an approval from the Australian Competition and Consumer Commission (ACCC) to establish a joint electricity purchasing group. The group accounts for 16% of South Australia's power demand. By combining their load of 263 MW, members sought to improve their bargaining power and secure reliable electricity supply at more competitive prices (ACCC, 2017).

However, despite potentially significant advantages, the negotiation of such industrial pooling arrangements can be challenging as there is competition among different mines and other industrial actors, as well as mismatches in location and operating horizons. This may explain the relative scarcity of sizeable examples of renewable energy industrial pooling in the mining industry to date (Votteler & Brent, 2016).

2.3. Mining companies entering low-carbon energy business

Mining companies have started recognising the business opportunities available in the use of low-carbon energy to generate electricity supply for customers, as well as satisfying their own operational needs. This includes the shared use of infrastructure with local communities, diversification of mining companies' portfolios towards renewables, as well as investment and participation in clean energy value chains, such as fuel cell technology.

Exploring opportunities for shared and post-closure use of mines' renewable energy infrastructure

In order to expand and prolong the use of renewable power plants, business opportunities are being explored to find additional demand for both off-grid and grid-connected systems. One such opportunity is to power local communities through the shared use of infrastructure, as highlighted by *Framework's* Step 3.1 (see Annex). Besides strengthening their social licence, selling power to communities can also generate an additional income stream for a mine.

Particularly pertinent are "off-grid" microgrid solutions for resource-rich countries, where mining operations often take place in remote rural locations, and where grid extension would be extremely expensive and economically unviable. For instance, Rio Tinto's 1.7 MW solar project at Weipa bauxite mine in Queensland, Australia powers a nearby township on Western Cape York Peninsula (Box 3.2), as well as the mine and its processing facilities. Similarly one of the rationales for government support to

Sandfire Resources' solar PV plant at DeGrussa mine was to explore opportunities for providing electricity to surrounding rural communities (OECD Development Centre, Compendium of Practices, 2017b).

Furthermore, mines have the strategic potential to act as an anchor consumer to help electrify remote off-grid communities, by generating the critical demand and the economies of scale required to connect these localities to the national grid (Banerjee et al., 2015; OECD, 2016). An example is Mauritania's SNIM that is currently working with the national utility company on the opportunities to connect its renewable energy power plants, which were originally built to supply its mining activities, to power the surrounding communities. This effort is well in line with the recommendations under the Framework's Step 3.2.1.A on the shared use of infrastructure, with mines acting as an anchor customer. However, several countries do not have adequate arrangements in place, which would allow selling excess power to local communities or the national grid, and therefore building an enabling policy environment is essential to harness the co-benefits (Section 3.1).

When encouraging the mining sector to contribute to improving countries' general energy access, it is important to ensure that government's and mining industry's efforts to power local communities are complementary to each other, with clear division of responsibilities. It is equally crucial to manage local communities' expectations of the mining industry and its ability to deliver socio-economic benefits beyond its core business. Participants in the Tenth Plenary Meeting of the Policy Dialogue highlighted the need for a compelling business case as an important prerequisite for mining companies to promote the shared use of their renewable energy infrastructure (OECD Development Centre, 2018).

Options for post-closure use

Even after the closure of a mine, electricity is often needed for land remediation, as well as to continue providing power to nearby communities, presenting another business opportunity for small off-grid or grid-connected power plants. For instance, consideration is being given to transferring the wind farm at the Diavik mine in the Northwest Territories, Canada after its closure to a nearby local community. The Diavik mine, owned by Rio Tinto and Dominion Diamond Corporation, will also share the experience with local communities in developing and maintaining a wind farm in subarctic conditions (CANWEA, 2013).

Similarly, as part of its corporate social responsibility strategy, B2Gold is considering options for using the 7 MW solar power plant that it is currently constructing for the Otjikoto mine in Namibia, in order to continue generating power for local communities after the gold mine's closure. This is a novel approach to ensuring that the positive social impact created by the mine outlasts its own lifetime. However, Namibia is an extremely sparsely populated country, with Oshikoto region – where the mine is located – having the population density of 4.7 people per square kilometre, according to the 2011 national census (NSA, 2011). Therefore, nearby communities might not be sufficiently large or close enough to the mine to create adequate demand for a plant with such significant generation capacity. B2Gold is exploring opportunities to connect the mine to the grid to reduce its reliance on heavy fuel oil (HFO), which the mine is currently fully dependent on at night. As a result, it might make economic sense to connect the mine and its solar PV plant to the grid, through a public-private effort, to reap the full benefit of the power plant for both the mine and domestic consumers (Mccloy, 2017).

Coal mining companies start diversifying into renewables

Renewable energy presents important business opportunities for coal mining companies. Coal India Limited (CIL), one of the world's largest coal producers, released a report *Coal Vision 2030* in 2018, which highlights the development of the renewable energy industry, which will create significant competition to the future of the coal sector (CIL, 2018). Later this year CIL announced its plan to invest in 20 GW renewable energy capacity over the next decade (Times of India, 2018).

Similarly, Exxaro, a South African coal company is exploring opportunities to diversify its portfolio to include renewables, through its Cennergi energy company – a 50:50 joint venture with India's Tata Power. In 2016, Exxaro built two utility-scale wind projects in the Eastern Cape – a 134 MW Amakhala Emoyeni wind farm and a 95 MW Tsitsikamma community wind farm. At the same time, however, Exxaro continues to invest in coal assets, with the estimated horizon for its coal business of another 40 years (Creamer, 2018).

Fuel cell technologies presents opportunities for platinum producers

Fuel cell technologies for clean energy generation, where platinum is used as a catalyst, present an opportunity to platinum group metals (PGMs) producers. Anglo American has become one of the steering members of the Hydrogen Council – a global company-led initiative seeking to harness the potential application of hydrogen in the global low-carbon energy transition, including in fuel cell technologies. The company's South Africa-based subsidiary, Anglo American Platinum, is exploring and testing applications for hydrogen and methanol fuel cell technologies. In partnership with Ballard Power Systems, the Department of Energy and Eskom, Anglo American Platinum started in 2014 a 12-month trial of methanol fuel cell prototype to provide electricity to 34 households in the Naledi Trust community in the Free State province of South Africa. It represented a welcome solution to the community that did not have access to the national grid. The project uses a commercially proven 5 kilowatt (kW) ElectraGenTM-ME fuel cell system, integrated with a battery bank and inverter into a micro-grid. The system relies on monthly delivery of liquid methanol fuel. The carbon-neutral setup can generate 15kW of electricity, and at peak times with the battery support up to 70kW (AngloAmerican South Africa, 2014).

Besides domestic consumption, fuel cell technologies can produce power for mining companies' own operations. In an effort to take its refinery in Springs near Johannesburg off the main Eskom grid, Impala Platinum built Doosan fuel cell plant. The 8 MW project was carried out in partnership with the Department of Trade and Industry and the Gauteng Industrial Development Zone, using domestically manufactured technology. Its key aim is to strengthen South Africa's platinum, as a value-added potential by manufacturing platinum-containing technology (Fuel Cells Bulletin, 2017).

3. Policy implications

3.1. Enabling policy environment for accelerated uptake of renewables in mining

As shown in Section 2, there is a compelling business case for integrating renewables in mining activities, building on the momentum created by the implementation of the Paris Agreement and the 2030 Agenda. However, despite the growing number of successfully delivered projects, several challenges persist for scaling up the sector's energy transition. A number of business models have emerged to meet mines' varying needs, with each approach offering certain advantages and limitations. The remaining financial, operational and policy-related risks, both for the mining industry and its renewable energy partners, may impede the mainstreaming of low-carbon power solutions throughout the mining industry.

In line with the recommendations of the OECD *Framework for Extractive Projects on Collaborative Strategies for In-Country Shared Value Creation* (Annex), as well as drawing on the *OECD Policy Guidance for Investment in Clean Energy Infrastructure*, the analysis of the 30 reviewed mining projects calls for an enabling policy and investment environment to accelerate the shift towards low-carbon energy generation. Chile provides an example of how the policy landscape can effectively support the use of renewables in mines (Box 3.1). It is key to achieving a market structure that promotes the synergistic development of the renewable energy sector and the emergence of business approaches, allowing for an optimal distribution of the risks involved for investors, mining and renewable energy companies, and the government. Moreover, an effective policy framework should be accompanied by a decisive paradigm shift in individual mining companies' business strategies towards a low-emission operating model.

Integrating changing energy needs of the mining sector into long-term national policies and mining companies' business strategies is essential for improved policy coherence

In order to align the mining sector with the objectives of the global energy transition, required to achieve the Paris Agreement and individual countries' Nationally Determined Contributions, the sector's current and future energy demands need to be understood and explicitly reflected in national energy and mining policies and strategies (*Framework's Step 1A.i; 3.2.1.A.i, ii)*. This would enable countries to plan for, and adapt national infrastructure to potential changes in the sector's energy needs. As an example, Tanzania has integrated its mining sector into the national Power System Master Plan 2016-2040, which distinguishes between short, medium and long-term horizons (MEM, 2016). This is particularly pertinent, in light of the growth of the clean technology sector, which is likely to increase demand for some rare earth elements and other metals and minerals, leading to the increase of mining activities. It is equally crucial that the need for the low-emission energy transition is clearly recognised in mining companies' business strategies, which will guide their performance in the coming decades, to ensure coherence with the changing international policy landscape.

Box 3.1. Learning from Chile's experience

Chile has emerged as a leader in deploying alternative energy solutions in the mining sector, which can be explained by a combination of factors. Firstly, the country has spectacular renewable energy potential, with the world's best solar resources located in Atacama Desert in the north and onshore wind resources (together with Argentina) in the south. In 2016, renewable energy accounted for nearly 40% of electricity generated, dominated by biomass and hydropower. While the share of solar and wind in the overall energy mix still remains below the country's potential (just over 6% in 2016), Chile has become a leading solar producer in the Latin American region.

Secondly, against the backdrop of abundant renewable energy resources, domestic production of fossil fuels is limited, with the majority of demand being met through imports. In response to Argentina's curtailment of natural gas exports in 2007, Chile has initiated efforts to reduce its dependence on fossil fuel imports and tap into domestic renewable energy resources.

The attractiveness of solar and wind solutions has gradually increased following severe weather conditions, such as recurring droughts, which have rendered hydropower relatively less reliable. Moreover, public discontent has put pressure on the future development of large-scale hydropower projects.

Thirdly, Chile's solar energy potential coincides with its non-renewable resources – Atacama Desert holds 30% of global copper reserves and significant non-metallic mineral reserves, including lithium, making the mining sector an important economic driver but also a consumer of energy. The Chilean mining sector creates significant energy demands (Section 1.1), with the copper industry alone consuming around 30% of the electricity generated.

Fourthly, an important factor in boosting the renewable energy sector is Chile's enabling policy environment, which has sent a strong signal to investors. Chile has a relatively de-regulated electricity market, having pioneered privatisation and restructuring reforms in the 1980s. More recently, the government has developed Chile Transforma – a series of strategic programmes aiming at the improvement of productivity of strategic sectors, including mining, and the promotion of innovation, the adoption of technology and the integration of solar energy. Under this framework, Chile has developed, through public-private collaboration, a mining technology roadmap 2035, which explicitly calls for the greater use of renewable energy by mining companies. Furthermore, the new energy efficiency law is likely to place additional pressure on mining companies to turn to renewables in order to reduce their energy usage and costs. Moreover, Chile has adopted in 2016 National Energy Policy 2050, developed through an extensive consultation process, which set ambitious renewable power targets of 60% by 2035 and 70% by 2050. The individual 20% target by 2025 set for companies in 2013 (Law 20.698) was met eight years ahead of time in 2017.

Finally, Chile has addressed a significant infrastructure challenges – its national grid expansion had fallen behind renewable energy growth, leading to transmission congestion in the Central Interconnected System (SIC) grid. The grid's overcapacity in the northern SIC put downward pressure on the spot market. Electricity prices, for generating companies, have been reduced by up to zero per MWh during daytime hours when solar power generation is at its peak. As a result, the further development of the renewable energy sector was at risk, since low spot market prices had an adverse impact on the bankability of renewable energy projects, increasing their cost of capital. To overcome the overcapacity challenge, in 2017 Chile's National Electric Coordinator (CEN) completed a major infrastructure project to connect the SIC with the Great Northern Interconnected System (SING). The latter is located in the north of the country and services a large share of industrial activities, in particular the mining sector. The further successful development of the Chilean renewable energy sector will depend on continued technological advancement, including storage solutions, regional inter-connection with neighbouring countries, and effective energy demand management.

Source: BNEF (2017), "Climatescope 2017. Country profile: Chile"; Energy and Mines (2016b), *Why Do Renewables Make Sense for Chilean Mines?*; Chile Transforma (2018); Fundación Chile (2016), *From Copper to Innovation: Mining Technology Roadmap 2035*; IEA (2018), *Energy Policies beyond IEA Countries – Chile 2018*; Ministry of Energy (2016), *Energy 2050: Chile's Energy Policy*; OECD/UN (2018), *Production Transformation Policy Review of Chile: Reaping the Benefits of New Frontiers*; Revista Electricidad (2017), "Interconexión SIC-SING partió sus operaciones dando vida al Sistema Eléctrico Nacional"; World Energy Council (2015), *World Energy Resources: Charting the Upsurge in Hydropower Development 2015*.

Government support is important to bridge remaining risk gaps

While renewable energy has become increasingly more competitive and there is a clear business case for its integration in mining activities, government support may be needed to overcome residual technological and financial barriers. Government may contribute to bridging remaining risk gaps in innovative pilot projects, particularly those that might otherwise not be implemented, but have significant potential to generate benefits for the economy and society in the future.

For example, in order to build investor confidence and overcome knowledge barriers, the Chilean Economic Development Agency (CORFO) has been subsidising up to half of the cost of pre-investment and pre-feasibility studies of renewable energy projects (OECD, 2016). At the same time, Canada's ecoENERGY Innovation Initiative was allocated USD 268 million with an aim to invest between 2011 and 2016 in research, development and demonstration projects in different areas, including clean electricity and renewables. As a result, ecoENERGY supported the construction of a 3 MW wind power plant for Glencore's Raglan mine in Quebec (Section 2.2).

The Australian Renewable Energy Agency (ARENA) through its Advancing Renewables Program provides support to the development and early-stage deployment of innovation projects that aim to lower the cost of renewable energy technologies and increase their uptake. ARENA's team, run by experienced investment and banking specialists, plays a key role in bringing projects to financial closure through expert advice and financial support (OECD Development Centre, Compendium of Practices, 2017b). Good examples are solar PV plants at Rio Tinto's Weipa mine in Queensland and at Sandfire Resources' DeGrussa mine in Western Australia (Box 3.2). ARENA's efforts also includes SunShift – a re-deployable solar power solution for hybrid systems (Section 2.2; Box 2.1).

Box 3.2. Australia – Federal government supports renewable energy projects in mines in Queensland and Western Australia

Rio Tinto's Weipa bauxite mine

Weipa bauxite mine, operated by Rio Tinto in Queensland, is Australia's first utility-scale renewable-powered mine, demonstrating the potential for integrating solar solutions in remote off-grid industrial activities. The two-phase project, with a total value of AUD 23.32 million, is owned by First Solar and supported by the ARENA. Rio Tinto is buying the power generated under a 15-year PPA.

In the first phase a 1.7 MW solar system was completed and integrated into 26 MW diesel power station in 2015. The system consists of 18 000 thin solar PV panels mounted on a steel and aluminium structures, and is connected to Rio Tinto's mini-grid. The project received AUD 3.5 million support from ARENA and supplies energy to the mine, its processing facilities as well as the local community. During the day, the plant can offset up to 20% of diesel-based electricity, with estimated annual diesel savings of 600 000 litres. The second phase will expand the generation capacity of the solar system to 6.7 MW and integrate battery storage. ARENA committed a further AUD 7.8 million to contribute to the funding of the second phase of the project (ARENA, 2015).

Rio Tinto is also building an Amrun bauxite mine, to the south of Weipa. While the mine is diesel-powered, it is built solar ready, with the potential of integrating a renewable energy system in the future.

Sandfire Resources NL's De Grussa copper mine

Drawing upon the experience of Rio Tinto's Weipa project, ARENA proceeded to support the construction of a 10.6 MW solar plant at the De Grussa mine, north of Perth, in Western Australia. One of the critical factors in the success of the project is the support provided by the two federal agencies. ARENA provided a recoupable grant of AUD 21 million towards the project, with a total value of AUD 40 million. The project was also successful in securing AUD 15 million in debt finance from the Clean Energy Finance Corporation.

ARENA also ensured co-ordination between various stakeholders in the project. It was responsible for the design, installation and integration of the power plant to complement diesel generation, as well as the maintenance of the hybrid system. To this end, ARENA supported the organisation of regular meetings for effective communication and the progress of the project (OECD Development Centre, Compendium of Practices, 2017b).

ARENA also supports peer learning, with the mining sector being among primary target audiences of its knowledge sharing efforts. For example, in June 2017, more than 60 mining professionals visited the DeGrussa mine to see the solar facility in operation and learn first-hand from the miners who had overseen its construction and the development of the project.

The solar farm is owned by Neoen. Juwi Renewable Energy is responsible for the project development, EPC and operation and maintenance. The electricity generated is sold to Sandfire Resources NL under a 5.5-year PPA. The solar system also includes a 4 MW battery storage, and is integrated into a 19 MW diesel power facility, which in turn is owned by a separate IPP – Kalgoorlie Power Systems. The technical setup allows the solar plant to meet the majority of the mine’s energy needs during the day, with the battery making up for drops in supply during short-term cloud coverage (ARENA, 2016b).

Source: ARENA (2016b), “DeGrussa solar project”; ARENA (2015), “Australia's first commercial diesel displacement solar plant starts operation”; OECD Development Centre, Compendium of Practices (2017b), “How can mining catalyse the deployment of off-grid solar energy?”.

International development finance

In addition to domestic government resources, multilateral development banks (MDBs) and bilateral development finance institutions (DFI) play a critical role in providing support to developing countries by bringing innovative and large-scale projects to financial closure. This may take the form of direct investment – debt, equity or mezzanine finance – either in market or concessional terms (OECD, 2018). For example, International Finance Corporation (IFC) and the Overseas Private Investment Corporation (OPIC) provided a USD 212.5 million non-recourse debt financing arrangement for the construction of a 100 MW solar PV plant in Atacama Desert developed by SunEdison to power the operations of CAP – Chilean mining and steel group (OPIC, 2013).

DFIs as well as export credit agencies may also provide guarantees as credit enhancement, to protect lenders against commercial or political risks, in case the guaranteed party fails to repay their debt. For example, in Chile, the German development co-operation agencies (GIZ and KfW) have implemented a number of renewable energy projects, with increasing focus on the mining sector to promote industrial application of low-carbon energy technologies. At the start, Chilean banks were reluctant to invest in renewable energy projects. In response, since 2008, CORFO in collaboration with KfW has been providing low-cost funding to commercial banks for financing renewable projects. In its first phase, the programme allocated nearly USD 140 million, mostly to small hydro projects. In 2011, the programme was extended by USD 90 million, and again in 2014, when it received USD 133 million to specifically target solar projects (OECD, 2016).

As more renewable energy projects were delivered, the Chilean domestic financial sector started to better understand the risk profiles involved and became increasingly willing to invest in such projects (OECD Development Centre, 2018). By 2015, around one third of Chilean banks were actively involved in financing renewables, including solar PV, wind and small hydro power projects (OECD, 2016). The increasing engagement of the Chilean domestic financial market shows the important role that development co-operation can play in building domestic investor confidence in the Chilean renewable energy sector, and improving the industry’s access to finance (OECD Development Centre, 2018).

As another example, funding for the development of the 115 MW El Arrayan wind plant, costing USD 245 million, was secured through a variety of sources, including guaranteed loans provided by Denmark’s export credit agency, Eksport Kredit Fonden (EKF). In addition, a banking consortium, advised by Milbank, and including Bank of Tokyo-Mitsubishi UFJ, Crédit Agricole and Sumitomo Mitsui Banking Corporation, provided a 15-year loan and a letter of credit facility. Finally, Chile's CorpBanca provided a USD 20 million subordinated loan facility to finance El Arrayan’s value-added tax payments (Milbank, 2012; PowerTechnology, 2018).

Furthermore, development co-operation providers offer scientific and technical expertise to governments and mining companies in developing countries. Importantly, development agencies can assist with collecting meteorological data regarding solar radiation and wind patterns, for a specific location, where the building of a power plant is contemplated. For example, in Mauritania, before announcing a tender, the government, in partnership with development co-operation agencies, had carried out a study to assess wind resources around Nouadhibou city, where it planned to build a wind farm to power SNIM's operations. The results of the assessment pointed to an advantageous wind speed, which lent itself to the successful development of the power plant (OECD Development Centre, 2018).

Determining a competitive energy market structure is key to enabling the mining sector's energy transition

An important factor in improving the uptake of renewable power solutions is a competitive industrial organisation of the energy market. The structure of a domestic power market should be conducive to the development of the renewable energy sector, supporting the emergence of experienced and credit worthy engineering, procurement and construction (EPCs) companies and IPPs for mining companies to partner with (Section 2.2). It should therefore be sufficiently liberalised to promote competition and allow IPP entry into generation, as well as private sector's involvement in other segments, including transmission functions (Banerjee et al., 2015; OECD, 2015a). In this context, governments should refrain from introducing mandatory local content requirements, which according to empirical evidence, might hamper the development of domestic and global solar and wind energy industries (OECD, 2015b). Instead, countries could make use of alternative policies which may prove more effective, such as supporting R&D and technology transfer, providing training programmes to fill local knowledge and skill gaps, and applying demand-side instruments, such as feed-in-tariffs, auctions or tax incentives (OECD, 2015a; 2015b).

Introducing and tightening carbon pricing mechanisms

To support and accelerate energy transition at the lowest possible cost and promote investment in clean power generation, the market structure needs to liberalise and should integrate effective regulation, such as carbon pricing, and green taxes on other air pollutants (IEA, 2016). Carbon pricing is a central policy instrument reflecting the social and economic cost of emissions. It also sends market signals to polluters, thereby improving the competitiveness of clean energy vis-à-vis fossil fuels. Carbon pricing includes a variety of tools, such as taxes on energy use, carbon taxes, emission trading systems and offset schemes. However, currently, over 60% of energy-related CO_2 emissions in G20 countries do not incur a carbon price, while less than 10% are priced at least at EUR 30 per tonne (a conservative lower bound estimate of the social cost of a tonne of CO_2 emissions) (OECD, 2017). In the absence of a strong carbon pricing signal, several mining companies have started applying a theoretical shadow price of carbon, to better assess risks and evaluate investments into long-term capital-intensive assets (Box 3.3).

Equally as important as the implementation of carbon pricing mechanisms, is the effective use of the potentially significant revenues raised, striking a balance between different policy priorities. A government might decide to spend these revenues on the promotion of economic growth, for example, through the reduction of the rate of taxes, on the improvement of social welfare and the reduction of inequality, or to spark green innovation through spending on R&D (OECD, 2017).

Box 3.3. The use of shadow prices of carbon by mining companies

When there is no strong carbon pricing signal, applying shadow prices of carbon can help guide corporate strategies in the lead up to potential future introduction or tightening of current carbon constraints. Based on the data collected by the Carbon Disclosure Project (CDP) from over 5 000 companies in 2016, 35% of the disclosers in the materials sector, which includes mining and metal businesses, have applied an internal price. For example, Anglo American and Anglo American Platinum reported an internal price in the range of USD 3.27–8.17 per tonne of CO_2 in the United Kingdom (UK) and South Africa, respectively whereas BHP Billiton used an internal price of USD 24 in the UK (CDP, 2016). BHP tends to generally use a shadow price in the range of USD 20-80 per tonne of CO_2, informed by a combination of factors, including technology, commodity prices, and explicit or implicit carbon prices embedded in the policies of a specific jurisdiction (Ahluwalia, 2017).

Sources: Ahluwalia, M.B (2017), "The business of pricing carbon: How companies are pricing carbon to mitigate risks"; CDP (2016), *Embedding a Carbon Price into Business Strategy.*

Ensuring adequate infrastructure can increase renewable energy penetration

It is equally critical to ensure the existence of the necessary infrastructure, particularly transmission networks, to accommodate renewable energy expansion. While decentralised power generation is presenting a solution for remote off-grid mines, larger-scale solar and wind projects require a grid connection, ensuring off-take of excess power (Banerjee et al., 2015). The quality and size of the electricity grid remains, therefore, a key factor in driving the overall growth and competition in the renewable energy sector, including for the mining industry (IEA, 2016).

Given that the expansion and improvement of transmission infrastructure takes significantly longer than building a renewable energy plant, it is urgent to understand and prepare for future infrastructure needs, driven by the energy transition. The experience of Chile demonstrates how a country's power grid infrastructure can lag behind the growth in renewables, leading to transmission congestion and impeding further investment in renewables (Box 3.1) (IEA, 2018).

Reforming fossil fuel subsidies can further improve renewables' competitiveness

Subsidies continue to be one of the key factors determining the competitiveness of renewable energy vis-à-vis fossil fuels. While global subsidies for fossil-fuel consumption saw a 15% decline in 2016, falling to USD 260 billion, they remained significantly higher than the support provided to renewable power generation – totalling USD 140 billion (IEA, 2017b).

Subsidies often aim at improving energy affordability for the poorest. However, deficiencies in design and targeting may result in wealthy consumers disproportionately benefitting, as it is they who have access to electricity and possess vehicles and appliances that consume fuel and power (IEA, 2017b). As a result, fossil fuel subsidies may unnecessarily burden government budgets and limit investment in renewables, impeding the shift to a cleaner, and often, more affordable energy mix. For example, global investments in fossil fuel supply and power generation totalled USD 825 billion in 2016, compared to USD 316 billion on renewables, including biofuels for transport and solar thermal heat (IEA, 2017c).

Therefore, government efforts to promote the use of renewables by energy-intensive mining activities should be considered in the broader policy context of incentives that may negatively affect the competitiveness of clean energy sources, compared to fossil fuels (OECD, 2015a).

3.2. Conclusions and further research

Mining activities are energy-intensive and have historically relied largely on fossil fuels, thereby exposing the mining sector to potential policy and regulatory risks. Collective government efforts to shift the global economy on a path of sustainable development resulted in an overall change in investment and consumption patterns and a call for major transformation of the mining industry, in order for the latter to maintain its competiveness in a low-carbon future.

In the context of the steady decline in the cost of renewable energy technology over the past years, solar and wind power solutions have become increasingly attractive to mines to reduce both their high energy costs as well as their carbon footprint. Several major mining companies have made use of renewables to power their operations, delivering a number of successful projects in off-grid and grid-connected mines. However, despite the existence of a compelling business case, a decisive shift of the whole mining industry towards a low-emission business model is yet to take place.

A number of business models – self-generation, corporate PPAs, rental and re-deployable solutions – have emerged to meet the varying needs of mines. Each approach offers certain advantages and limitations. Overall, as a relatively new technology in the mining context, renewable energy may pose a number of operational and financial risks. Given the important upfront capital investment associated with renewable energy systems, the bankability of these projects presents a central challenge to mining companies or the IPPs they contract with. Furthermore, a shift to low-carbon energy sources implies the synergistic development of a strong renewable energy sector, which is often contingent on an enabling policy environment.

In order to scale up the integration of renewables in mining, the following are key factors: the adoption of a competitive market structure, the promotion of renewable energy investment and an optimal distribution of the associated risks between investors, mining companies, renewable energy companies, and the government. Other key policy areas requiring heightened attention include: integrating the mining sector's energy needs into long-term national policies; ensuring the existence of adequate energy infrastructure; reforming fossil fuel subsidies; and providing support to bridging remaining risk gaps for continued technological advancement and innovation. It is equally crucial that the need for low-emission energy transition is clearly recognised in mining companies' business strategies that will guide their performance in the coming decades. This will ensure they remain coherent with the changing international policy landscape and the global energy transition priorities, as envisaged by the Paris Agreement and the 2030 Agenda.

Suggested areas for future analysis

While this paper has focused predominantly on the integration of renewables to meet electricity demand for both grid-connected and off-grid mining activities, there are several areas which would benefit from further research. First, there is a need to explore the industrial application of renewables in processing activities which, as discussed in Section 1.1, are extremely energy-intensive. Metal processing facilities are likely to be located in areas with a grid connection. However these might not always offer a reliable supply of cost-competitive electricity. Renewable energy might help address some of these challenges, when combined with storage systems that potentially allow processing facilities to be located in rural off-grid areas closer to mines.

There is also a need to better understand the impact the global low-emission transition will have on the future development of the mining sector and the environment. Driven by clean technology, a heightened demand for some minerals and metals may create additional environmental and climate change-related pressures, thereby increasing the demand for green mining operations and efforts to promote a circular economy.

Future research could also contribute to building a knowledge base on the use of solar thermal energy solutions in mining and processing industries. Some existing research (e.g. Beath, 2012) and industry experience (see OECD Development Centre, Compendium of Practices, 2017c; Section 2.2) point to the significant potential to using solar thermal energy in mining as well as in the oil sector. However, to date, examples of solar thermal application in extractive activities remain limited (Table 2.1). Research on the pace of electrification and the automation of mining operations, as mentioned in Section 1.2, paves the way to an accelerated transition to renewables. This research would also be useful for the comprehensive contextual understanding of the sector’s energy transition. Finally, improved knowledge of the mining companies' energy transition efforts in different regions will be of great interest. Mining companies tend to provide aggregate data on the integration of renewables in their operations, with limited geographic granularity. Given that socio-economic conditions and policy frameworks can vary significantly across jurisdictions, it would be important to understand how the companies operating internationally respond to these varying circumstances. We hope that this analysis will generate opportunities for peer learning between countries, as well as for knowledge sharing among mining companies.

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Annex

Excerpt of relevant recommendations from *Framework for Extractive Projects on Collaborative Strategies for In-Country Shared Value Creation*

STEP 1. Adopt a comprehensive long-term vision and implementation strategy to build competitive and diversified economies and create in-country shared value out of natural resources.

1.A. What can host governments do?

i. Develop sustainable options for energy production and consumption, also assessing trade-offs and combined use of renewable and non-renewable resources.

STEP 3.2.1. Shared power

3.2.1.A. What can host governments do?

i. Obtain extractives sector projects' projections for power demand, and preferred sources to allow for early planning and effective co-ordination amongst relevant central, and local authorities.
ii. Take a long-term perspective when identifying potential synergies, taking into due account any rising demand from non-extractives sector sources. Also, assess the affordability to communities and their willingness to pay, and plan sustainable provision beyond the conclusion of the extractives sector project.
iii. When extractives sector operations are used as anchor customers for large power developments, design appropriate power pricing mechanisms to avoid either subsidising the extractives sector at the expense of the utility or taxpayers, or decreasing the supply available to non-extractives sector industries and residential consumers.
iv. Consider partners other than the extractives sector in development of power generation capacity to incentivise the construction of oversized generation plants to serve neighbouring populations, or send excess capacity from self-supply to the grid.

3.2.1.B. What can extractives industries do?

i. Provide forecasts regarding anticipated demand for power and sourcing of power, and regularly provide data about actual usage.

Where there is no grid or the grid is too remote so that grid-supplied electricity is more expensive or excessively unreliable compared with self-supply:

ii. Develop electricity self-supply plans that align with government's plans for electrification and local contexts.
iii. When planning to supply local communities with power, consult early with the local communities to understand their power needs and preferences, defining their responsibilities and those of the local government in operating and maintaining power arrangements including access fees.
iv. Enable a sustainable strategy for leveraging extractives sector energy generation, by assessing the feasibility of renewable energy power generation options.

v. In consultation with donors, governments, and utilities, assess the feasibility of installing a renewable energy-based mini grid instead of isolated generators and explore implementation and cost-sharing arrangements.

vi. Where economically viable, collaborate with other extractives companies from the same basin to invest in power generation and transmission capacity, considering domestic needs, including non-industrial use.

Where electricity provided by the utility is stable and less expensive than self-supplied power:

vii. Buy electricity from the grid, while working with national or local public utilities and other extractives companies to upgrade generation, transmission, and distribution capacity to meet demand.

3.2.1.C. Host governments and extractives industries can work together to:

i. Undertake early discussions regarding power infrastructure needs and plans to determine if there are synergies, efficiencies and other opportunities for shared value creation with respect to power generation and distribution. This includes developing strategies for situations where there is no ready access to the electricity grid.

ii. For any project undertaken, clearly articulate government and company responsibilities and liabilities, including operating and maintenance, power transmission and delivery, billing and customer revenue management.

STEP 4. Support and contribute to innovation leading to new products and services

4.A. What can host governments do?

i. Support research and development efforts to identify, adapt, and transfer technology, making sure that these efforts are responsive to private sector demands.

4.B. What can extractives industries do?

i. Leverage extractives sector operations to increase use of renewable energy, as appropriate. This could be done for example by either linking production to renewable energy (e.g. making use of solar and wind power to reduce the contribution of fossil fuels and green-house gases to mineral and oil and gas production, while reducing high electricity costs associated with the use of decentralised diesel generators) or by developing green supply chains (e.g. mining rare earths and supporting local manufacturing of magnets for wind turbines to provide clean energy or mining lithium to manufacture electric batteries for incorporation into green products).

Source: OECD (2016), *Collaborative Strategies for In-Country Shared Value Creation: Framework for Extractive Projects*, OECD Development Policy Tools, OECD Publishing, Paris. http://dx.doi.org/10.1787/9789264257702-en